

## DESCRIPTION

## POWER OUTPUT APPARATUS FOR HYBRID VEHICLE

## 5 Technical Field

The present invention relates to a power output apparatus, an automobile, and methods of controlling the same.

## Background Art

10 A proposed power output apparatus has an internal combustion engine, a planetary gear unit that includes a carrier linked with an output shaft of the internal combustion engine and a ring gear linked with a drive shaft, a generator that inputs and outputs power to and from a sun gear of the  
15 planetary gear unit, and a motor that inputs and outputs power to and from the drive shaft (see, for example, Japanese Patent Laid-Open Gazette No. H11-55810). In the case of heat generation in the generator or its driving circuit, this prior art apparatus decreases the output torque of the internal  
20 combustion engine and raises the revolution speed of the internal combustion engine, so as to reduce the load of the generator and prevent the heat generation in the generator while maintaining a power demand to be output from the internal combustion engine.

25 In the power output apparatus that independently drives the internal combustion engine and the drive shaft, in the case

of the occurrence of some disturbance like overheat of the generator, the drive point of the internal combustion engine is changed to respond to the disturbance while keeping the power demand to be output from the internal combustion engine  
5 unchanged. Keeping the power demand to be output from the internal combustion engine unchanged maintains the driving force to be output to the drive shaft. When the motor that outputs power to the drive shaft is under a drive restriction due to heat generation in the motor or its driving circuit,  
10 however, the technique of keeping the power demand to be output from the internal combustion engine unchanged may make the output from the internal combustion engine significantly greater than the output to the drive shaft and may cause an accumulator like a secondary battery to be excessively charged.

15

#### Disclosure of the Invention

The power output apparatus, the automobile, and their control methods of the invention aim to prevent an accumulator like a secondary battery from being excessively charged under  
20 a drive restriction of a motor that is capable of outputting power to a drive shaft. The power output apparatus, the automobile, and their control methods of the invention also aim to ensure output of a power in the range of the drive restriction to the drive shaft under the drive restriction of  
25 the motor. The power output apparatus, the automobile, and their control methods of the invention further aim to improve

the emission under the drive restriction of the motor.

In order to attain at least part of the above aims, the power output apparatus, the automobile, and their control methods are constructed as follows.

5           A first power output apparatus of the present invention is an apparatus that outputs power to a drive shaft, the power output apparatus including: an internal combustion engine; an electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine  
10   and with the drive shaft and outputs at least part of power from the internal combustion engine to the drive shaft through inputs and outputs of electric power and mechanical power; a motor that is capable of inputting and outputting power from and to the drive shaft; an accumulator that is capable of  
15   supplying and receiving electric power to and from the electric power-mechanical power input-output module and the motor; a power demand setting module that sets a power demand required to the drive shaft, in response to an operator's manipulation; a target power setting module that sets a target power to be  
20   output from the internal combustion engine, based on the setting of the power demand; a drive restriction effectuation module that, when a predetermined restricting condition is fulfilled, effects a drive restriction of the motor based on the predetermined restricting condition; a correction module  
25   that corrects the setting of the target power based on the effected drive restriction, when the drive restriction of the

motor is effected by the drive restriction effectuation module;  
and a control module that executes normal control of  
controlling the internal combustion engine, the electric  
power-mechanical power input-output module, and the motor in  
5 the case of no effectuation of the drive restriction of the  
motor by the drive restriction effectuation module to ensure  
output of the target power from the internal combustion engine  
and output of a power corresponding to the setting of the power  
demand to the drive shaft, the control module executing  
10 restriction control of controlling the internal combustion  
engine, the electric power-mechanical power input-output  
module, and the motor in the case of effectuation of the drive  
restriction of the motor by the drive restriction effectuation  
module to ensure output of the corrected target power from the  
15 internal combustion engine and output of a power in a range  
of the effected drive restriction from the motor.

Under no drive restriction of the motor, the first power  
output apparatus of the invention controls the internal  
combustion engine, the electric power-mechanical power  
20 input-output module, and the motor to ensure output of the  
target power from the internal combustion engine and output  
of a power corresponding to the power demand to the drive shaft.  
Under the drive restriction of the motor, on the other hand,  
the first power output apparatus corrects the target power  
25 based on the drive restriction and controls the internal  
combustion engine, the electric power-mechanical power

input-output module, and the motor to ensure output of the corrected target power from the internal combustion engine and output of a power in the drive restriction from the motor. Namely, the target power is corrected to change the drive point  
5 of the internal combustion engine under the drive restriction of the motor. The arrangement of the invention effectively prevents the accumulator from being excessively charged and ensures output of the power in the range of the drive restriction to the drive shaft. This desirably prevents  
10 deterioration of the emission by output of a power corresponding to the power demand from the internal combustion engine under the drive restriction of the motor.

In one preferable embodiment of the invention, the first power output apparatus further includes a charge-discharge  
15 electric power measurement module that measures a charge-discharge electric power used to charge the accumulator or obtained by discharging the accumulator; and an electric power demand setting module that sets an electric power demand for charging or discharging the accumulator, based on a  
20 predetermined charge-discharge condition. The correction module corrects the target power to cancel a difference between the charge-discharge electric power measured by the charge-discharge electric power measurement module and the electric power demand set by the electric power demand setting  
25 module. The electric power used to charge the accumulator or obtained by discharging the accumulator thus significantly

approaches to the electric power demand. This arrangement effectively prevents the accumulator from being excessively charged.

In one preferable application of the first power output  
5 apparatus of the invention, the target power setting module specifies a target torque and a target revolution speed to set the target power, and the correction module varies the specified target revolution speed to correct the target power. The drive point of the internal combustion engine is thus  
10 changed, while the torque output from the internal combustion engine is kept unchanged. This arrangement desirably reduces the effects of a varying output of the power to the drive shaft by the electric power-mechanical power input-output module with a variation in target power.

15 In another preferable application of the first power output apparatus of the invention, the control module executes the restriction control on a condition that the power demand is in a predetermined light load power range, when the drive restriction of the motor is effected by the drive restriction  
20 effectuation module. Such control is restrictively executed in a light load state, while different control is adopted in a heavy load state. This arrangement ensures adequate control in response to the operator's requirement.

A second power output apparatus of the present invention  
25 is an apparatus that outputs power to a drive shaft, the power output apparatus including: an internal combustion engine; an

electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine and with the drive shaft and outputs at least part of power from the internal combustion engine to the drive shaft through  
5 inputs and outputs of electric power and mechanical power; a motor that is capable of inputting and outputting power from and to the drive shaft; an accumulator that is capable of supplying and receiving electric power to and from the electric power-mechanical power input-output module and the motor; and  
10 a control module that sets a power demand required to the drive shaft in response to an operator's manipulation and sets a target power to be output from the internal combustion engine based on the setting of the power demand, the control module controlling the internal combustion engine, the electric  
15 power-mechanical power input-output module, and the motor in the case of no fulfillment of a predetermined restricting condition to ensure output of the target power from the internal combustion engine and output of a power corresponding to the power demand to the drive shaft, in the case of fulfillment  
20 of the predetermined restricting condition, the control module effecting a drive restriction of the motor based on the predetermined restricting condition, correcting the setting of the target power based on the effected drive restriction, and controlling the internal combustion engine, the electric  
25 power-mechanical power input-output module, and the motor to ensure output of the corrected target power from the internal

combustion engine and output of a power in a range of the effected drive restriction from the motor.

Under no drive restriction of the motor, the second power output apparatus of the invention controls the internal combustion engine, the electric power-mechanical power input-output module, and the motor to ensure output of the target power from the internal combustion engine and output of a power corresponding to the power demand to the drive shaft. Under the drive restriction of the motor, on the other hand, the second power output apparatus corrects the target power based on the drive restriction and controls the internal combustion engine, the electric power-mechanical power input-output module, and the motor to ensure output of the corrected target power from the internal combustion engine and output of a power in the drive restriction from the motor. Namely, the target power is corrected to change the drive point of the internal combustion engine under the drive restriction of the motor. The arrangement of the invention effectively prevents the accumulator from being excessively charged and ensures output of the power in the range of the drive restriction to the drive shaft. This desirably prevents deterioration of the emission by output of a power corresponding to the power demand from the internal combustion engine under the drive restriction of the motor.

In the first or the second power output apparatus discussed above, the electric power-mechanical power



input-output module may include: a three-shaft power input-output assembly that is connected with three shafts, that is, the output shaft of the internal combustion engine, the drive shaft, and a third shaft, and specifies input and output  
5 of power from and to one residual shaft among the three shafts, based on powers input and output from and to two shafts among the three shafts; and a generator that inputs and outputs power from and to the third shaft. In the first or the second power output apparatus discussed above, the electric  
10 power-mechanical power input-output module may include a pair-rotor generator having a first rotor, which is linked with the output shaft of the internal combustion engine, and a second rotor, which is linked with the drive shaft and rotates relative to the first rotor, the pair-rotor generator outputting at  
15 least part of the power from the internal combustion engine to the drive shaft through input and output of electric power by electromagnetic interaction between the first rotor and the second rotor.

The power output apparatus of any application mentioned  
20 above may be mounted on an automobile. Specifically, an automobile of the present invention includes: an internal combustion engine; an electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine and with a drive shaft coupled with  
25 an axle and outputs at least part of power from the internal combustion engine to the drive shaft through inputs and outputs

of electric power and mechanical power; a motor that is capable of inputting and outputting power from and to the drive shaft; an accumulator that is capable of supplying and receiving electric power to and from the electric power-mechanical power input-output module and the motor; a power demand setting module that sets a power demand required to the drive shaft, in response to an operator's manipulation; a target power setting module that sets a target power to be output from the internal combustion engine, based on the setting of the power demand; a drive restriction effectuation module that, when a predetermined restricting condition is fulfilled, effects a drive restriction of the motor based on the predetermined restricting condition; a correction module that corrects the setting of the target power based on the effected drive restriction, when the drive restriction of the motor is effected by the drive restriction effectuation module; and a control module that executes normal control of controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of no effectuation of the drive restriction of the motor by the drive restriction effectuation module to ensure output of the target power from the internal combustion engine and output of a power corresponding to the setting of the power demand to the drive shaft, the control module executing restriction control of controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in

the case of effectuation of the drive restriction of the motor by the drive restriction effectuation module to ensure output of the corrected target power from the internal combustion engine and output of a power in a range of the effected drive  
5 restriction from the motor. Another automobile of the present invention includes: an internal combustion engine; an electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine and with the drive shaft coupled with an axle and outputs at least part of  
10 power from the internal combustion engine to the drive shaft through inputs and outputs of electric power and mechanical power; a motor that is capable of inputting and outputting power from and to the drive shaft; an accumulator that is capable of supplying and receiving electric power to and from the  
15 electric power-mechanical power input-output module and the motor; and a control module that sets a power demand required to the drive shaft in response to an operator's manipulation and sets a target power to be output from the internal combustion engine based on the setting of the power demand,  
20 the control module controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of no fulfillment of a predetermined restricting condition to ensure output of the target power from the internal combustion engine and output of a power  
25 corresponding to the power demand to the drive shaft, in the case of fulfillment of the predetermined restricting condition,

the control module effecting a drive restriction of the motor based on the predetermined restricting condition, correcting the setting of the target power based on the effected drive restriction, and controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor to ensure output of the corrected target power from the internal combustion engine and output of a power in a range of the effected drive restriction from the motor.

In one preferable embodiment of the invention, one of the automobiles discussed above further includes: a charge-discharge electric power measurement module that measures a charge-discharge electric power used to charge the accumulator or obtained by discharging the accumulator; and an electric power demand setting module that sets an electric power demand for charging or discharging the accumulator, based on a predetermined charge-discharge condition. The correction module corrects the setting of the target power to cancel a difference between the charge-discharge electric power measured by the charge-discharge electric power measurement module and the electric power demand set by the electric power demand setting module. In one preferable application of the automobiles discussed above, the target power setting module specifies a target torque and a target revolution speed to set the target power, and the correction module may vary the specified target revolution speed to correct the target power. In another preferable application

of the automobile discussed above, the control module executes the restriction control on a condition that the power demand is in a predetermined light load power range, when the drive restriction of the motor is effected by the drive restriction  
5 effectuation module.

The technique of the power output apparatus and the automobile with the power output apparatus mounted thereon of the present invention is also applicable to a control method for a power output apparatus or for an automobile. A control  
10 method of the present invention is a method for a power output apparatus or an automobile, that includes: an internal combustion engine; an electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine and with a drive shaft and outputs  
15 at least part of power from the internal combustion engine to the drive shaft through inputs and outputs of electric power and mechanical power; a motor that is capable of inputting and outputting power to and from the drive shaft; and an accumulator that is capable of supplying and receiving electric power to  
20 and from the electric power-mechanical power input-output module and the motor, the control method including the steps of: (a) setting a power demand required to the drive shaft, in response to an operator's manipulation; (b) setting a target power to be output from the internal combustion engine, based  
25 on the setting of the power demand; (c) when a predetermined restricting condition is fulfilled, effecting a drive

restriction of the motor based on the predetermined restricting condition; (d) correcting the setting of the target power based on the effected drive restriction, in the case of effectuation of the drive restriction of the motor; and (e) controlling the  
5 internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of no effectuation of the drive restriction of the motor to ensure output of the target power from the internal combustion engine and output of a power corresponding to the setting of the power  
10 demand to the drive shaft, while controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of effectuation of the drive restriction of the motor to ensure output of the corrected target power from the internal combustion engine and  
15 output of a power in a range of the effected drive restriction from the motor.

In one preferable embodiment of the invention, the control method further includes, prior to the step (d), the steps of: (f) measuring a charge-discharge electric power used  
20 to charge the accumulator or obtained by discharging the accumulator; and (g) setting an electric power demand for charging or discharging the accumulator, based on a predetermined charge-discharge condition. The step (d) corrects the target power to cancel a difference between the  
25 observed charge-discharge electric power and the setting of the electric power demand.

### Brief Description of the Drawings

Fig. 1 schematically illustrates the construction of a hybrid vehicle 20 in one embodiment of the invention; Fig. 2 is a flowchart showing a drive control routine executed by a hybrid electronic control unit 70; Fig. 3 shows an example of a torque demand setting map; Fig. 4 shows an example of a driving line of an engine 22 and a process of setting a target revolution speed  $N_e^*$  and a target torque  $T_e^*$ ; Fig. 5 is an alignment chart showing a dynamic relation with respect to a rotational elements in a power distribution integration mechanism 30; Fig. 6 is a flowchart showing a light load correction routine; Fig. 7 is a flowchart showing a heavy load correction routine; Fig. 8 shows a driving line of the engine 22 and a process of correcting a target drive point; Fig. 9 shows the relation between power of the engine 22 and power of a motor MG2 in an ordinary state and under drive restriction of the motor MG2; Fig. 10 shows a process of correcting the target drive point according to a heavy load driving line; Fig. 11 schematically illustrates the construction of a hybrid vehicle 120 in one modified embodiment; and Fig. 12 schematically illustrates the construction of a hybrid vehicle 220 in another modified embodiment.

### Best Modes of Carrying Out the Invention

One mode of carrying out the invention is discussed below as a preferred embodiment. Fig. 1 schematically illustrates

the construction of a hybrid vehicle 20 with a power output apparatus mounted thereon in one embodiment of the invention. As illustrated, the hybrid vehicle 20 of the embodiment includes an engine 22, a three shaft-type power distribution integration mechanism 30 that is linked with a crankshaft 26 functioning as an output shaft of the engine 22 via a damper 28, a motor MG1 that is linked with the power distribution integration mechanism 30 and is capable of generating electric power, a reduction gear 35 that is attached to a ring gear shaft 32a functioning as a drive shaft connected with the power distribution integration mechanism 30, another motor MG2 that is linked with the reduction gear 35, and a hybrid electronic control unit 70 that controls the whole power output apparatus.

The engine 22 is an internal combustion engine that consumes a hydrocarbon fuel, such as gasoline or light oil, to output power and is under control of an engine electronic control unit (hereafter referred to as engine ECU) 24. The engine ECU 24 receives input signals from various sensors detecting the driving conditions of the engine 22 and carries out operation control including fuel injection control, ignition control, and intake air flow regulation. The engine ECU 24 communicates with the hybrid electronic control unit 70 and receives control signals from the hybrid electronic control unit 70 to control the operations of the engine 22, while outputting data regarding the driving conditions of the engine 22 to the hybrid electronic control unit 70 according



to the requirements.

The power distribution and integration mechanism 30 has a sun gear 31 that is an external gear, a ring gear 32 that is an internal gear and is arranged concentrically with the sun gear 31, multiple pinion gears 33 that engage with the sun gear 31 and with the ring gear 32, and a carrier 34 that holds the multiple pinion gears 33 in such a manner as to allow free revolution thereof and free rotation thereof on the respective axes. Namely the power distribution and integration mechanism 30 is constructed as a planetary gear mechanism that allows for differential motions of the sun gear 31, the ring gear 32, and the carrier 34 as rotational elements. The carrier 34, the sun gear 31, and the ring gear 32 in the power distribution and integration mechanism 30 are respectively coupled with the crankshaft 26 of the engine 22, the motor MG1, and the reduction gear 35 via the ring gear shaft 32a. While the motor MG1 functions as a generator, the power output from the engine 22 and input through the carrier 34 is distributed into the sun gear 31 and the ring gear 32 according to the gear ratio. While the motor MG1 functions as a motor, on the other hand, the power output from the engine 22 and input through the carrier 34 is combined with the power output from the motor MG1 and input through the sun gear 31 and the composite power is output to the ring gear 32. The power output to the ring gear 32 is finally transmitted to the driving wheels 63a, 63b via the gear mechanism 60 and differential gear 62 from ring gear shaft 32a.

Both of the motors MG1 and MG2 are constructed as known synchronous generator motors, which are driven as an electric generator as well as an electric motor. The motors MG1 and MG2 transmit electric power from and to a battery 50 via  
5 inverters 41 and 42. A power line 54 connecting the inverters 41 and 42 with the battery 50 includes a positive terminal bus line and a negative terminal bus line shared by the two inverters 41 and 42. This arrangement enables the electric power generated by one of the motors MG1 and MG2 to be consumed  
10 by the other motor. The battery 50 is charged with the excess electric power of the motor MG1 or the motor MG2 and is discharged to supplement the insufficient electric power of the motor MG1 or the motor MG2. The battery 50 is neither charged not discharged when there is an electric power balance  
15 by the motors MG1 and MG2. The motors MG1 and MG2 are both driven and controlled by a motor electronic control unit (hereinafter referred to as motor ECU) 40. The motor ECU 40 receives signals required for driving and controlling the motors MG1 and MG2, for example, signals from rotational  
20 position detection sensors 43 and 44 that detect the rotational positions of rotors in the motors MG1 and MG2 and values of phase electric currents supplied to the motors MG1 and MG2 and detected by non-illustrated electric current sensors. The motor ECU 40 outputs switching control signals to the inverters  
25 41 and 42. The motor ECU 40 communicates with the hybrid electronic control unit 70 and drives and controls the motors

MG1 and MG2 in response to control signals from the hybrid electronic control unit 70 while outputting data regarding the driving conditions of the motors MG1 and MG2 to the hybrid electronic control unit 70 according to the requirements.

5           The battery 50 is controlled by a battery electronic control unit (hereinafter referred to as battery ECU) 52. The battery ECU 52 receives signals required for controlling the battery 50, for example, a value of inter-terminal voltage  $V_b$  measured by a voltage sensor 51a disposed between terminals  
10 of the battery 50, a value of charge discharge electric current  $I_b$  measured by an electric current sensor 51b attached to the power line 54 connecting with an output terminal of the battery 50, and a battery temperature  $T_b$  measured by a temperature sensor 51c attached to the battery 50. The battery ECU 52  
15 outputs data regarding the conditions of the battery 50 to the hybrid electronic control unit 70 via communication according to the requirements. The battery ECU 52 computes a state of charge (SOC) from an accumulated value of the charge discharge electric current  $I_b$  measured by the electric current sensor  
20 51b for controlling the battery 50.

          The hybrid electronic control unit 70 is constructed as a microprocessor including a CPU 72, a ROM 74 that stores processing programs, a RAM 76 that temporarily stores data, and a non-illustrated input-output port, and a non-illustrated  
25 communication port. The hybrid electronic control unit 70 receives various inputs via the input port: a motor temperature

T<sub>m</sub> from a temperature sensor 46 attached to the motor MG2, an inverter temperature T<sub>inv</sub> from a temperature sensor 47 attached to the inverter 42, an ignition signal from an ignition switch 80, a gearshift position SP from a gearshift position sensor 82 that detects the current position of a gearshift lever 81, an accelerator opening Acc from an accelerator pedal position sensor 84 that measures a step-on amount of an accelerator pedal 83, a brake pedal position BP from a brake pedal position sensor 86 that measures a step-on amount of a brake pedal 85, and a vehicle speed V from a vehicle speed sensor 88. The hybrid electronic control unit 70 communicates with the engine ECU 24, the motor ECU 40, and the battery ECU 52 via the communication port to transmit diverse control signals and data to and from the engine ECU 24, the motor ECU 40, and the battery ECU 52, as mentioned previously.

The hybrid vehicle 20 of the embodiment thus constructed calculates a required torque, which is to be output to the ring gear shaft 32a or the drive shaft, based on the accelerator opening Acc corresponding to the driver's step-on amount of the accelerator pedal 83 and the vehicle speed V. The engine 22 and the motors MG1 and MG2 are under operation control to enable power corresponding to the calculated required torque to be actually output to the ring gear shaft 32a. The operation control of the engine 22 and the motors MG1 and MG2 has multiple modes, a torque conversion drive mode, a charge-discharge drive mode, and a motor drive mode. In the torque conversion drive

mode, the engine 22 is under operation control to output a power equivalent to the required power. The motors MG1 and MG2 are driven and controlled to cause the total power output from the engine 22 to be subjected to the torque conversion by means of the power distribution and integration mechanism 30 and the motors MG1 and MG2 and to be output to the ring gear shaft 32a. In the charge-discharge drive mode, the engine 22 is under operation control to output a power equivalent to the sum of the required power and an electric power used for charging and discharging the battery 50. The motors MG1 and MG2 are driven and controlled to cause all or part of the power output from the engine 22 with a charge or a discharge of the battery 50 to be subjected to the torque conversion by means of the power distribution and integration mechanism 30 and the motors MG1 and MG2 and to be output as the required power to the ring gear shaft 32a. In the motor drive mode, the operation of the engine 22 is at a stop, while the motor MG2 is driven and controlled to output a power equivalent to the required power to the ring gear shaft 32a.

The following describes the operations of the hybrid vehicle 20 of the embodiment constructed as discussed above, especially the operation under a drive restriction of the motor MG2 due to a temperature rise of the motor MG2 or the inverter 42. Fig. 2 is a flowchart showing a drive control routine executed by the hybrid electronic control unit 70. This routine is carried out repeatedly at preset time intervals (for

example, at every 8 msec).

When the drive control routine starts, the CPU 72 of the hybrid electronic control unit 70 first inputs various data required for control, that is, the accelerator opening Acc from the accelerator pedal position sensor 84, the vehicle speed V from the vehicle speed sensor 88, revolution speeds Nm1 and Nm2 of the motors MG1 and MG2, and a drive limit Tlim of the motor MG2 (step S100). The procedure of this embodiment receives the revolution speeds Nm1 and Nm2 of the motors MG1 and MG2, which have been calculated according to rotational positions of rotors in the motors MG1 and MG2 detected by rotational position detection sensors 43 and 44, from the motor ECU 40 via communication. The procedure of this embodiment reads out and inputs the drive limit Tlim of the motor MG2, which has been set according to a non-illustrated drive limit setting routine based on the motor temperature Tm from the temperature sensor 46 attached to the motor MG2, the inverter temperature Tinv from the temperature sensor 47 attached to the inverter 42, and the revolution speed Nm2 of the motor MG2 and has been written at a specified address in the RAM 76. The drive limit Tlim is set, for example, as a value of 60% or 50% of a rated maximum torque of the motor MG2 at the revolution speed Nm2, when the motor temperature Tm or the inverter temperature Tinv is not lower than an upper limit motor temperature or an upper limit inverter temperature set as the upper threshold to ensure continuous actuation of the motor

MG2. In this embodiment, when the motor temperature  $T_m$  or the inverter temperature  $T_{inv}$  is lower than the upper limit motor temperature or the upper limit inverter temperature, a rated maximum torque of the motor MG2 at a revolution speed  $N_e$  is set to the drive limit  $T_{lim}$ . For the better understanding of explanation, the following description first regards the procedure without a drive restriction of the motor MG2 and the procedure under a drive restriction of the motor MG2.

After the input of these data, the CPU 72 sets a torque demand  $Tr^*$  to be output to the ring gear shaft 32a or the drive shaft linked with the drive wheels 63a and 63b as the torque required for the vehicle and a power demand  $Pe^*$  to be output from the engine 22, based on the inputs of the accelerator opening  $Acc$  and the vehicle speed  $V$  (step S110). In the structure of this embodiment, variations in torque demand  $Tr^*$  against the accelerator opening  $Acc$  and the vehicle speed  $V$  are specified in advance and stored as a torque demand setting map in the ROM 74. The procedure of the embodiment reads and sets the torque demand  $Tr^*$  corresponding to the given accelerator opening  $Acc$  and the given vehicle speed  $V$  from the stored torque demand setting map. Fig. 3 shows an example of the torque demand setting map. The power demand  $Pe^*$  is calculated as the sum of the product of the setting of the torque demand  $Tr^*$  and a revolution speed  $N_r$  of the ring gear shaft 32a, a charge-discharge power demand  $Pb^*$  of the battery 50, and a potential loss 'Loss'. The revolution speed  $N_r$  of the

ring gear shaft 32a may be obtained by multiplying the vehicle speed  $V$  by a conversion coefficient  $k$  or by dividing the revolution speed  $Nm2$  of the motor MG2 by a gear ratio  $Gr$  of the reduction gear 35.

5        After setting the torque demand  $Tr^*$  and the power demand  $Pe^*$ , a target revolution speed  $Ne^*$  and a target torque  $Te^*$  of the engine 22 are set according to the setting of the power demand  $Pe^*$  (step S120). Here the target revolution speed  $Ne^*$  and the target torque  $Te^*$  are set according to a driving line  
10       for efficiently driving the engine 22 and the setting of the power demand  $Pe^*$ . An example of the driving line of the engine 22 and the process of setting the target revolution speed  $Ne^*$  and the target torque  $Te^*$  are shown in Fig. 4. As illustrated, the target revolution speed  $Ne^*$  and the target torque  $Te^*$  are  
15       obtained as the intersection of the driving line and a curve of constant power demand  $Pe^*$  ( $= Ne^* \times Te^*$ ).

      After setting the target revolution speed  $Ne^*$  and the target torque  $Te^*$ , it is determined whether the motor MG2 is under a drive restriction (step S130). The presence of the  
20       drive restriction of the motor MG2 may be specified according to the value of the drive limit  $Tlim$  or according to the value of a flag, which may be set to effect the drive restriction of the motor MG2.

      The description first regards the case without a drive  
25       restriction of the motor MG2. The routine thus gives a negative answer in this cycle at step S130 and goes to the processing



of and after step S170. The CPU 72 calculates a target revolution speed  $Nm1^*$  of the motor MG1 from the setting of the target revolution speed  $Ne^*$ , the revolution speed  $Nr (= Nm2/Gr)$  of the ring gear shaft 32a, and a gear ratio  $p$  of the power distribution integration mechanism 30 according to Equation (1) given below, while calculating a torque command  $Tm1^*$  of the motor MG1 from the calculated target revolution speed  $Nm1^*$  and the current revolution speed  $Nm1$  according to Equation (2) given below (step S170). Equation (1) shows a dynamic relation of the rotational elements in the power distribution integration mechanism 30. Fig. 5 is an alignment chart showing a dynamic relation between the revolution speed and the torque with respect to the rotational elements in the power distribution integration mechanism 30. An axis S shows the revolution speed of the sun gear 31 that is equal to the revolution speed  $Nm1$  of the motor MG1. An axis C shows the revolution speed of the carrier 34 that is equal to the revolution speed  $Ne$  of the engine 22. An axis R shows the revolution speed  $Nr$  of the ring gear 32 that is obtained by multiplying the revolution speed  $Nm2$  of the motor MG2 by the gear ratio  $Gr$  of the reduction gear 35. Equation (1) is easily derived from this alignment chart. Two thick arrows on the axis R respectively represent a torque acting on the ring gear shaft 32a as a torque  $Te^*$  output from the engine 22 is transmitted via the power distribution integration mechanism 30 while the engine 22 is steadily driven at a specific drive

point defined by the target torque  $T_e^*$  and the target revolution speed  $N_e^*$ , and a torque acting on the ring gear shaft 32a as a torque  $T_{m2}^*$  output from the motor MG2 is transmitted via the reduction gear 35. Equation (2) shows a relation in feedback control to rotate the motor MG1 at the target revolution speed  $N_{m1}^*$ . In Equation (2), 'k1' in the second term on the right side represents a gain of a proportional term and 'k2' in the third term on the right side represents a gain of an integral term.

10

$$N_{m1}^* = N_e^* \cdot (1+\rho)/\rho - N_{m2}/(Gr \cdot \rho) \quad (1)$$

$$T_{m1}^* = \text{Previous } T_{m1}^* + k_1(N_{m1}^* - N_{m1}) + k_2 \int (N_{m1}^* - N_{m1}) dt \quad (2)$$

After calculation of the target revolution speed  $N_{m1}^*$ , and the torque command  $T_{m1}^*$  of the motor MG1, the CPU 72 divides a difference between an output limit  $W_{out}$  of the battery 50 and a power consumption (generated power) of the motor MG1, which is the product of the calculated torque command  $T_{m1}^*$  of the motor MG1 and the current revolution speed  $N_{m1}$  of the motor MG1, by the current revolution speed  $N_{m2}$  of the motor MG2 according to Equation (3) given below to calculate a torque limit  $T_{max}$  as an upper limit torque output from the motor MG2 (step S180). The CPU 72 also calculates a tentative motor torque  $T_{m2tmp}$  as a torque to be output from the motor MG2 from the torque demand  $T_r^*$ , the torque command  $T_{m1}^*$ , and the gear ratio  $\rho$  of the power distribution integration mechanism 30

according to Equation (4) given below (step S190), and sets the smallest among the calculated torque limit  $T_{max}$ , the calculated tentative motor torque  $T_{m2tmp}$ , and the drive limit  $T_{lim}$  to a torque command  $T_{m2*}$  of the motor MG2 (step S200).

5 In this cycle of the routine, there is no drive restriction of the motor MG2. The rated maximum torque of the motor MG2 at the revolution speed  $N_e$  has accordingly been set to the drive limit  $T_{lim}$ . Setting the torque command  $T_{m2*}$  of the motor MG2 in this manner enables the torque demand  $T_r^*$ , which is to be  
10 output to the ring gear shaft 32a or the drive shaft, to be set as a restricted torque in the range of the output limit of the battery 50 and by the rated maximum torque of the motor MG2. Equation (4) is easily derived from the alignment chart of Fig. 5 discussed above.

15

$$T_{max} = (W_{out} - T_{m1*} \cdot N_{m1}) / N_{m2} \quad (3)$$

$$T_{m2tmp} = (T_r^* + T_{m1*} / \rho) / G_r \quad (4)$$

After setting the target revolution speed  $N_e^*$  and the  
20 target torque  $T_e^*$  of the engine 22 and the torque commands  $T_{m1*}$  and  $T_{m2*}$  of the motors MG1 and MG2, the CPU 72 sends the target revolution speed  $N_e^*$  and the target torque  $T_e^*$  of the engine 22 to the engine ECU 24 and the torque commands  $T_{m1*}$  and  $T_{m2*}$  of the motors MG1 and MG2 to the motor ECU 40 (step S210) and  
25 exits from this drive control routine. The engine ECU 24 receives the target revolution speed  $N_e^*$  and the target torque

Te\* and carries out fuel injection control and ignition control of the engine 22 to drive the engine 22 at a drive point defined by the target revolution speed Ne\* and the target torque Te\*. The motor ECU 40 receives the torque commands Tm1\* and Tm2\* and carries out switching control of switching elements in the inverters 41 and 42 to drive the motor MG1 with the torque command Tm1\* and to drive the motor MG2 with the torque command Tm2\*.

In the case with a drive restriction of the motor MG2, on the other hand, the routine gives an affirmative answer at step S130 and determines whether the input accelerator opening Acc is not greater than a preset reference opening Aref (step S140). The preset reference opening Aref is used to determine whether the driver requires a heavy load to the vehicle and is set equal to, for example, 30% or 40%. When the input accelerator opening Acc is not greater than the preset reference opening Aref, the CPU 72 specifies a light load state and executes a light load correction routine shown in the flowchart of Fig. 6 to correct a target drive point of the engine 22 defined by the target revolution speed Ne\* and the target torque Te\* (step S150). When the input accelerator opening Acc is greater than the preset reference opening Aref, on the contrary, the CPU 72 specifies a heavy load state and executes a heavy load correction routine shown in the flowchart of Fig. 7 to correct the target drive point of the engine 22 defined by the target revolution speed Ne\* and the target torque Te\*

(step S160).

The light load correction routine first reads observed charge-discharge electric powers  $W_b$  and a charge-discharge electric power demand  $W_b^*$  of the battery 50 (step S300) and  
5 calculates an average charge-discharge electric power  $W_{bave}$  of the observed charge-discharge electric powers  $W_b$  read in a preset time period (for example, in 1 second) (step S310). Here the observed charge-discharge electric power  $W_b$  of the battery 50 is obtained as the product of a voltage  $V_b$  between  
10 terminals of the battery 50 measured by a voltage sensor 51a and a charge-discharge current  $I_b$  measured by a current sensor 51b and is input from the battery ECU 52 via communication. The charge-discharge electric power demand  $W_b^*$  is obtained by conversion of the charge-discharge power demand  $P_b^*$ . The  
15 routine then calculates a difference (electric power difference)  $\Delta W$  between the charge-discharge electric power demand  $W_b^*$  and the calculated average charge-discharge electric power  $W_{bave}$  (step S320) and corrects the target revolution speed  $Ne^*$  of the engine 22 to cancel the electric  
20 power difference  $\Delta W$  (step S330). The procedure of this embodiment adds the product of the electric power difference  $\Delta W$  and a proportional gain  $k_b$  to a previous value of the target revolution speed  $Ne^*$  set in the previous cycle, so as to correct the target revolution speed  $Ne^*$ . The light load correction  
25 routine varies the target revolution speed  $Ne^*$  at the target drive point of the engine 22 to cancel the difference between

the charge-discharge electric power demand  $Wb^*$  and the calculated average charge-discharge electric power  $Wave$ , that is, to make the observed charge-discharge electric power  $Wb$  of the battery 50 equal to the charge-discharge electric power demand  $Wb^*$ , while keeping the target torque  $Te^*$  unchanged. Fig. 8 shows a driving line of the engine 22 and a process of correcting the target drive point of the engine 22. Fig. 9 shows the relation between the power of the engine 22 and the power of the motor MG2 in the ordinary state and under the drive restriction of the motor MG2. As shown in Fig. 8, the target drive point of the engine 22 is changed from a drive point DP1, which is the intersection of a driving line of the engine 22 and a curve of constant power demand  $Pe^*$ , to a drive point DP2 of a lower target revolution speed  $Ne^*$ . The power output from the engine 22 is thus equal to the product of the corrected target revolution speed  $Ne^*$  and the target torque  $Te^*$  of the drive point DP2. The charge-discharge electric power  $Wb$  of the battery 50 under the drive restriction of the motor MG2 is thus equal to that in the ordinary state, as shown in Fig. 9.

20 9.

The heavy load correction routine sets the target revolution speed  $Ne^*$  and the target torque  $Te^*$  of the engine 22 as the intersection of a heavy load driving line and the curve of constant power demand  $Pe^*$  (step S400 in Fig. 7). Fig. 10 shows a process of correcting the target drive point according to a heavy load driving line. As illustrated, the

target drive point of the engine 22 is changed from a drive point DP1, which is the intersection of an ordinary state driving line and a curve of constant power demand  $Pe^*$ , to a drive point DP3, which is the intersection of a heavy load driving line and the curve of constant power demand  $Pe^*$ .  
5 Changing the target drive point to increase the target torque  $Te^*$  in this manner enhances the torque  $(Te^*/(1+p))$  transmitted to the ring gear shaft 32a among the torque to be output from the engine 22 (the target torque  $Te^*$ ). A torque that is still  
10 smaller than but is closer to the torque demand  $Tr^*$  can thus be output to the ring gear shaft 32a or the drive shaft under the drive restriction of the motor MG2.

On completion of the correction of the target drive point of the engine 22, the routine executes the processing of steps  
15 S170 to S200 to set the torque commands  $Tm1^*$  and  $Tm2^*$  of the motors MG1 and MG2. In this cycle of the routine, there is a drive restriction of the motor MG2. The drive limit  $Tlim$  has thus been set as 60% or 50% of the rated maximum torque of the motor MG2 at the revolution speed  $Ne$ . The processing  
20 of step S200 sets the smallest among the torque limit  $Tmax$ , the tentative motor torque  $Tm2tmp$ , and the drive limit  $Tlim$  to the torque command  $Tm2^*$  of the motor MG2. The torque command  $Tm2^*$  of the motor MG2 is accordingly set by restricting the torque demand  $Tr^*$  to be output to the ring gear shaft 32a or  
25 the drive shaft in the range of the output limit of the battery 50 and in the drive restriction of the motor MG2.

The target revolution speed  $Ne^*$  and the target torque  $Te^*$  of the engine 22 corrected as discussed above and the settings of the torque commands  $Tm1^*$  and  $Tm2^*$  of the motors MG1 and MG2 are respectively sent to the engine ECU 24 and the motor ECU 40 (step S210). The engine ECU 24 and the motor ECU 40 control the engine 22 and the motors MG1 and MG2 to ensure output of the torque command  $Tm1^*$  from the motor MG1 and output of the torque command  $Tm2^*$  from the motor MG2 and thereby to drive the engine 22 at the target drive point defined by the target revolution speed  $Ne^*$  and the target torque  $Te^*$ .

As described above, the hybrid vehicle 20 of the embodiment corrects the target drive point of the engine 22 to make the observed charge-discharge electric power  $Wb$  of the battery 50 equal to the charge-discharge electric power demand  $Wb^*$ , while keeping the torque of the engine 22 unchanged, during a drive in the light load state and under the drive restriction of the motor MG2. This arrangement effectively prevents the battery 50 from being excessively charged and deterioration of the emission. During a drive in the heavy load state and under the drive restriction of the motor MG2, the hybrid vehicle 20 corrects the target drive point of the engine 22 to increase the target torque  $Te^*$ . A torque that is still smaller than but is rather closer to the torque demand  $Tr^*$  can thus be output to the ring gear shaft 32a or the drive shaft. This arrangement ensures output of a desired torque in response to the driver's manipulation even under the drive restriction of the motor MG2.



In the absence of a drive restriction of the motor MG2, the torque demand  $Tr^*$  is output to the ring gear shaft 32a or the drive shaft in the range of the output limit  $W_{out}$  of the battery 50 and in the range of the rated maximum torque.

5       The hybrid vehicle 20 of the embodiment effects the drive restriction of the motor MG2 when the temperature  $T_m$  of the motor MG2 or the temperature  $T_{inv}$  of the inverter 42 is not lower than the upper limit motor temperature or the upper limit inverter temperature. The drive restriction of the motor MG2  
10       may be effected according to any suitable factor other than the temperature  $T_m$  of the motor MG2 or the temperature  $T_{inv}$  of the inverter 42.

      In the hybrid vehicle 20 of the embodiment, the drive limit  $T_{lim}$  of the motor MG2 is set as 60% or 50% of the rated  
15       maximum torque of the motor MG2 at the revolution speed  $Nm2$ . The drive limit  $T_{lim}$  is not restricted to the value 60% or 50% but may be greater or smaller. The drive limit  $T_{lim}$  may be a variable that has a stricter restriction with an increase in temperature  $T_m$  of the motor MG2 or an increase in temperature  
20        $T_{inv}$  of the inverter 42.

      In the hybrid vehicle 20 of the embodiment, under the drive restriction of the motor MG2 and in the heavy load state, the target drive point of the engine 22 is changed to the drive point DP3, which is the intersection of the heavy load driving  
25       line and the curve of constant power demand  $Pe^*$ . Another technique may alternatively be applied to set the target drive

point.

In the hybrid vehicle 20 of the embodiment, the power of the motor MG2 is subjected to gear change by the reduction gear 35 and is output to the ring gear shaft 32a. In one possible modification shown as a hybrid vehicle 120 of Fig. 11, the power of the motor MG2 may be output to another axle (that is, an axle linked with wheels 64a and 64b), which is different from an axle connected with the ring gear shaft 32a (that is, an axle linked with the wheels 63a and 63b).

In the hybrid vehicle 20 of the embodiment, the power of the engine 22 is output via the power distribution integration mechanism 30 to the ring gear shaft 32a functioning as the drive shaft linked with the drive wheels 63a and 63b. In another possible modification of Fig. 12, a hybrid vehicle 220 may have a pair-rotor motor 230, which has an inner rotor 232 connected with the crankshaft 26 of the engine 22 and an outer rotor 234 connected with the drive shaft for outputting the power to the drive wheels 63a, 63b and transmits part of the power output from the engine 22 to the drive shaft while converting the residual part of the power into electric power.

The embodiment discussed above is to be considered in all aspects as illustrative and not restrictive. There may be many modifications, changes, and alterations without departing from the scope or spirit of the main characteristics of the present invention. The scope and spirit of the present invention are indicated by the appended claims, rather than

by the foregoing description.

#### Industrial Applicability

The technique of the invention is applicable to the  
5 automobile industry and the drive system manufacturing  
industry.